410 Rec'd PCT/PTO 05 MAY 2000

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| FORM PTO-1390 (REV 5-93) | U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE | ATTORNEY'S DOCKET NUMBER 2345/129 |
| **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371** | | U.S. APPLICATION NO. (If known, see 37 CFR 1.5) 09/530934 |
| INTERNATIONAL APPLICATION NO. PCT/EP98/04789 | INTERNATIONAL FILING DATE (31.07.98) 31 July 1998 | PRIORITY DATE CLAIMED: (06.11.97) 06 November 1997 |

TITLE OF INVENTION
**METHOD AND CIRCUIT ARRANGEMENT FOR IMPROVED DATA TRANSMISSION**

APPLICANT(S) FOR DO/EO/US
**HUBER, Klaus**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

**Items 11. to 16. below concern other document(s) or information included:**

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
    ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: Preliminary Examination Report and International Search Report.

EXPRESS MAIL NO. EL179106621US

| U.S. APPLICATION NO (if known, see 37 C.F.R 1.5) 09/530934 | INTERNATIONAL APPLICATION NO PCT/EP98/04789 | ATTORNEY'S DOCKET NUMBER 2345/129 |
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17. ☒ The following fees are submitted:

**Basic National Fee (37 CFR 1.492(a)(1)-(5)):**

Search Report has been prepared by the EPO or JPO .................. $840.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) ... $670.00

No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) ............. $760.00

Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO ........................ $970.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) ........................ $96.00

CALCULATIONS | PTO USE ONLY

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| **ENTER APPROPRIATE BASIC FEE AMOUNT =** | | | | $ 840 | |
| Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)). | | | | $ | |
| Claims | Number Filed | Number Extra | Rate | | |
| Total Claims | 17 - 20 = | 0 | X $18.00 | $ 0 | |
| Independent Claims | 2 - 3 = | 0 | X $78.00 | $ 0 | |
| Multiple dependent claim(s) (if applicable) | | | + $260.00 | $ 0 | |
| **TOTAL OF ABOVE CALCULATIONS =** | | | | $ 840 | |
| Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28). | | | | $ | |
| **SUBTOTAL =** | | | | $ 840 | |
| Processing fee of $130.00 for furnishing the English translation later the ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). + | | | | $ | |
| **TOTAL NATIONAL FEE =** | | | | $ 840 | |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property + | | | | $ | |
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| | | | | charged | $ |

a. ☐ A check in the amount of $________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of **$840.00** to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

**NOTE:** Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

By: Des Magnt (Reg. No. 41,172)

Richard L. Mayer

SIGNATURE

SEND ALL CORRESPONDENCE TO:

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Method and Circuit Arrangement for Improved Data Transmission

09/530934
422 Rec'd PCT/PTO 05 MAY 2000

[2345/129]

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT: HUBER, Klaus

SERIAL NO.: to be assigned

FILED: herewith

TITLE: METHOD AND CIRCUIT ARRANGEMENT FOR IMPROVED DATA TRANSMISSION

ART UNIT: not yet known

EXAMINER: not yet known



Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

PRELIMINARY AMENDMENT

Please amend the above-identified application before a first consideration on the merits as follows:

IN THE DRAWINGS

Please replace Figs. 4 and 5 with amended Figs. 4 and 5 submitted herewith.

IN THE TITLE

Please amend the title to read --METHOD AND CIRCUIT ARRANGEMENT FOR DATA TRANSMISSION--.

IN THE SPECIFICATION

On page 1, before line 1, insert --Field of the Invention--.

On page 1, line 1, before "invention" insert --present-- and after "data" insert



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--transmission for efficient use of multi-level modulation processes which employ orthogonal basis functions to represent a signal to be transmitted.--.

On page 1, before line 4, insert --Related Technology--.

On page 1, line 8, after "3" insert --, which is hereby incorporated by reference herein--.

On page 2, line 12, after "300" insert --, which is hereby incorporated by reference herein--.

On page 2, before line 17, insert --Summary of the Invention--.

On page 4, line 24, change "the object" to --an object-- and before "invention" insert --present--.

On page 2, delete lines 23-30.

On page 3, delete lines 1-4.

On page 3, before line 6, insert --The present invention provides a method for data transmission using a multi-level modulation process to represent a signal for transmission, the multi-level modulation process using at least one orthogonal basis function. Signal points of a signal constellation are selected according to at least one respective predetermined and/or selected probability so as to optimize a respective signal energy and/or a respective signal data rate, the selected signal points each having a respective defined energy.

The present invention also provides a circuit arrangement for data transmission using a multi-level modulation process, the multi-level modulation process using at least one orthogonal function, the circuit arrangement including a data source for providing a data stream; a recoder downstream of the data source; a modulator for selecting signal points of a signal constellation according to at least one respective predetermined and/or selected probability so as to optimize a respective signal energy and/or a respective signal data rate, the selected signal points each having a defined respective energy, the modulator being connected to an output of the recoder; a transmission channel, an input of the transmission channel being connected to an output of the modulator; a demodulator, an input of the demodulator being connected to an output of the transmission channel; an inverse recoder for executing the operation inverse to that of the recoder, an input of the inverse recoder being connected to the demodulator; and a data sink, an input of the sink being connected to an output of the inverse

recoder.--.

On page 3, line 6, change "described here" to --according to the present invention--.

On page 3, line 17, change "(0,+-(1+$\sqrt{3}$)/2" to --(0,+-(1+$\sqrt{3}$)/2)--.

On page 3, line 18, change "approx." to --approximately--.

On page 3, delete line 20 ---.

On page 3, line 21, change "the recoding," to --With a method according to the present invention recoding is-- and change "accomplish, if" to --accomplish when--.

On page 4, line 19, after "are" insert --revealed below--.

On page 4, delete lines 20-24.

On page 4, before line 26, insert --Brief Description of the Drawings--.

On page 4, line 26, before "invention" insert --present-- and change "on the basis of exemplary" to --with reference to the drawings, in which:--.

On page 4, line 29, after "shows" insert --a graphical representation of--.

On page 5, line 1, after "shows" insert --a graphical representation of--.

On page 5, line 3, change "3+6 show" to --3 shows-- and delete "used".

On page 5, line 8, after "points" insert --shown-- and delete "and".

On page 5, line 11, change "vice versa." to --vice versa; and--.

On page 5, before line 13, insert --

Fig. 6 shows a block diagram of a circuit arrangement for improved data transmission with the aid of the efficient use of multilevel modulation methods with recoder control as a function of temporary storage and with a second data source and second data sink.

Detailed Description--.

On page 5, line13, change "was already stated" to --stated above--.

On page 6, line 12, after "1098-1101" insert --, which is hereby incorporated by reference herein--.

On page 6, line 30, change "energy 3" to --energy 3;--.

On page 7, line 3, delete "the construction of" and change "implementing the"to --improved data transmission with the aid of the efficient use of multilevel modulation methods.--.

On page 7, line 11, before "recoder" insert --inverse--.

On page 7, line 4, delete "above-described method" and change "a block" to --the block--.

On page 7, line 24, delete "(known)".

On page 8, line 16, change "the most common case," to --a block diagram of a circuit arrangement according to an embodiment of the present invention--.

On page 8, line 30, change "To further improve the method, it is possible to use" to --In other embodiments of the present invention--.

On page 9, line 1, change "constellations and" to --may be used.--.

On page 9, line 2, change "which can be found in the articles" to --Such special coding methods may be found, for example, in--.

On page 9, line 8, after "740-744" insert --, both of which are hereby incorporated by reference herein--.

On page 10, delete all lines.

On page 11, line 1, change "Patent Claims" to --WHAT IS CLAIMED IS:--.

IN THE CLAIMS

Please cancel without prejudice claims 1-15 and add new claim 16-32 as follows:

--16. (new) A method for data transmission comprising:

using a multi-level modulation process to represent a signal for transmission, the multi-level modulation process using at least one orthogonal basis function; and

selecting signal points of a signal constellation according to at least one respective predetermined and/or selected probability so as to optimize a respective signal energy and/or a respective signal data rate, the selected signal points each having a respective defined energy.

17. (new The method as recited in claim16 further comprising using at least one source coding process for adapting a data sequence of the signal for the using of the at least one orthogonal basis function.

18. (new) The method as recited in claim 17 wherein the at least one source coding process includes a Huffman method.

19. (new) The method as recited in claim 16 further comprising using a first data source to provide the signal for transmission and using at least one source coding process for adapting a data sequence of the signal for the using of the at least one orthogonal basis function, the at least one source coding process including an error-correcting code adapted to the modulation process and a respective transmission channel for protection against transmission errors, error detection characters of the modulation process being inserted using a second data source.

20. (new) The method as recited in claim 19 wherein the error-correcting code includes a block code.

21. (new) The method as recited in claim 19 wherein the error-correcting code includes a convolution code.

22. (new) The method as recited in claim 20 wherein the block code includes a code over Gaussian integers modulo a Gaussian number.

23. (new) The method as recited in claim 20 wherein the block code includes a code over Eisenstein-Jacobi integers modulo an Eisenstein-Jacobi number.

24. (new) The method as recited in claim 16 wherein that the signal for transmission includes an encrypted input data stream.

25. (new) A method as recited in claim 16 further comprising selecting a first data rate for the transmission channel that is greater than a second data rate of the data stream.

26. (new) The method as recited in claim 16 further comprising transmitting synchronization data during at least one time when no bits are present in the signal for

transmission.

27. (new) The method as recited in claim 16 further comprising transmitting at least one of housekeeping data and user data when no bits are present in the signal for transmission.

28. (new) A circuit arrangement for data transmission using a multi-level modulation process, the multi-level modulation process using at least one orthogonal function, the circuit arrangement comprising:

a data source for providing a data stream;

a recoder downstream of the data source;

a modulator for selecting signal points of a signal constellation according to at least one respective predetermined and/or selected probability so as to optimize a respective signal energy and/or a respective signal data rate, the selected signal points each having a defined respective energy, the modulator being connected to an output of the recoder;

a transmission channel, an input of the transmission channel being connected to an output of the modulator;

a demodulator, an input of the demodulator being connected to an output of the transmission channel;

an inverse recoder for executing a first operation inverse to a second operation of the recoder, an input of the inverse recoder being connected to the demodulator; and

a data sink, an input of the sink being connected to an output of the inverse recoder.

29. (new) The circuit arrangement as recited in claim 28 further comprising:

a temporary storage device including a control/processing unit, the temporary storage device being capable of triggering the recoder to switch between at least two recoding tables so that there is no storage overflow;

a second temporary storage device including a second control/processing unit disposed between the inverse recoder and the sink; and

a second data sink connected to the second temporary storage device.

30. (new) The circuit arrangement as recited in claim 28 wherein the output of the

modulator is connected in a buffered manner to the input of the transmission channel.

31. (new) The circuit arrangement as recited in claim 30 wherein the output of the modulator is connected in a buffered manner to the input of the transmission channel via at least one of a temporary register and a buffer.

32. (new) The circuit arrangement as recited in claim 28 further comprising:

a temporary storage device capable of triggering the recoder to switch between at least two recoding tables so that there is no storage overflow; and

a second data source for providing the temporary storage with at least one of user data, synchronization data and check data.--.

IN THE ABSTRACT

Line 1, change "The invention relates to a" to --A--.

Line 3, after "transmitted." insert --Signal points of a signal constellation are selected according to a respective predetermined and/or selected probabilities so as to optimize a respective signal energy and/or a respective signal data rate, the selected signal points each having a defined respective energy.--.

Line 4, change "instance, in a simple and optional way," to --example,-- and change "The circuit" to --In the circuit--.

Line 5, change "arrangement corresponding to said method comprises" to --arrangement,--.

Line 8, change "with the right probability" to --according to the respective probabilities--.

## REMARKS

This Preliminary Amendment cancels original claims 1-15 and adds new claims 16-32. The new claims do not add new matter to the application but do conform the claims to U.S. Patent and Trademark Office rules.

The amendments to the specification, abstract and drawings are to conform the specification, abstract and drawings to U.S. Patent and Trademark Office rules. It is

respectfully submitted that the amendments to the specification, abstract and drawings do not introduce new matter into the application.

The underlying PCT application includes a Search Report, a copy of which is included herewith.

Conclusion

Consideration of the present application as amended is hereby respectfully requested.

Respectfully Submitted,

Kenyon & Kenyon

Dated: 5/5/00

By: ______________________

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[2345/129]

# METHOD AND CIRCUIT ARRANGEMENT FOR IMPROVED DATA TRANSMISSION

The invention relates to a method and a circuit arrangement for improved data transmission according to the preambles of Claim 1 and Claim 9, respectively.

In telecommunications engineering, transmission methods are known, and also used in practice, which utilize orthogonal basis functions to represent the signal to be transmitted. Such transmission methods are described, for example, in the book of R.E. Blahut, *Digital Transmission of Information*, Addison-Wesley, Reading, 1990, chapters 2 and 3.

In this case, a message signal s(t) in the baseband is represented as the sum of orthogonal basis functions. In order to integrate the message $m = (m_0, m_1, m_2 \ldots m_{k-1})$ - where the $m_j$ are selected from an appropriately chosen alphabet - into the signal s(t), the signal is formed as follows:

$$s(t) = m_0 f_0(t) + m_1 f_1(t) + \ldots + m_{K-1}\, f_{K-1}\,(t).$$

Consequently, a message signal can be regarded as a point in a K-dimensional space and specifically is characterized by the value-tuple $(m_0, m_1, \ldots, m_{K-1})$. The entirety of all permissible signals is referred to as a signal constellation. Especially popular in practice are two-dimensional signal constellations, such as the so-called 16-QAM signal constellation shown in Fig. 1 of the present application. This 16-QAM signal constellation is described, for example, in the aforementioned book on page 63. In all the signal constellations considered here, it is assumed that the minimum distance between two signal points is normalized to 1. However, the known transmission methods for efficient use of multi-level modulation methods do not yet permit the

optimal utilization of the signal energy of signal constellations. First of all, signal constellations which are very efficient may, however, have the disadvantage that the number of signal points is not a power of two and, secondly, frequently employed signal constellations, such as 16-QAM, cannot yet be used in simple and optimal manner to transmit low data rates.

Fundamental theoretical investigations on improved data transmission and on the efficient use of multi-level modulation methods employing orthogonal basis functions to represent a signal to be transmitted and using, for example, the known Huffman method as a source coding method have been published in F.R. Kschischang, S. Pasupathy, "*Optimal Nonuniform Signaling for Gaussian Channels*", IEEE Transactions on Information Theory, Vol. 39, No. 3, May 1993, pp. 281-300. However, practical implementations of these investigations in the form of circuit arrangements and/or corresponding methods for operating such circuit arrangements have not been specified.

Therefore, the object of the invention is to provide a method and a circuit arrangement for improved data transmission with efficient use of multi-level modulation methods which permit optimal use of the signal energy of signal constellations and by which frequently employed signal constellations, such as 16-QAM, can be used in simple and optimal manner to transmit lower data rates.

The objective of the invention with regard to the method is achieved by the method described in the characterizing part of Claim 1.

Further design approaches or refinements of the method are described in Claims 2 through 8 and 12 through 15.

The objective of the invention with regard to the circuit arrangement is achieved by the circuit arrangement described in the characterizing part of Claim 9 and a further

refinement is described in the characterizing parts of Claims 10 through 12.

Further design approaches and refinements of the invention are indicated in the following detailed description.

The method and the circuit arrangement described here permit optimal utilization of the signal energy of signal constellations. This can be of advantage for technical applications in two respects. First of all, signal constellations which are very efficient, but have the disadvantage that the number of signal points is not a power of two, can now be adapted in a simple manner to data formats used in practice, such as a bit sequence. Secondly, frequently employed signal constellations, such as 16-QAM, can be used in simple and optimal manner to transmit lower data rates. Thus, the 16-QAM signal constellation can be used to transmit on average 3 bits per signal point, instead of the usual 4 bits per signal point. This can be technically useful, for example, in order to switch to 16-QAM with optimized probabilities in existing transmitters and receivers using, for instance, 8-QAM with the points { (+-1/2, +-1/2), (+-(1+√3)/2,0), (0,+-(1+√3)/2 } as signal constellation (i.e. 3 bits per signal point), accompanied by simultaneous power gain of approx. 1 dB.

The method has a further characteristic which can be put to advantageous use. This is the recoding, particularly simple to accomplish, if the input data stream is a uniformly distributed sequence, especially a bit sequence. The recoding can then be accomplished using a loss-free decompression method such as the Huffman method. Accordingly, the inverse recoding operation on the receiver end is carried out using the corresponding compression method. A uniformly distributed sequence or bit sequence is obtained, for example, by encryption. This means that the possibly bothersome guarantee or generation of such a sequence can be achieved by the addition of a value-added operation, namely encryption. Since encryption will play an ever greater role in future transmission systems and is already being supplied today along with many systems, the new method is particularly practical. In the recoding of

the incoming source bit stream to the signal points which are transmitted through the channel, use is made of a temporary register as buffer that serves to adapt the bit rate, which fluctuates as a function of time due to the transmission through the channel, to the bit rate of the source data. In an implementation of the circuit, this temporary register has a defined fixed length. In practice, this leads to the problem of a "buffer overflow". To solve this problem, the suggestion here is to select the channel data rate to be greater than the source data rate, it being advantageous to select the channel data rate to be slightly greater than the source data rate. In this manner, it is possible, with relatively little effort and expense, to specify the length of the temporary register or the length of the buffer so that there is only a negligibly small (known) probability of an overflow. When working with a channel data rate which is greater than the source data rate, it may occur that the channel will be ready to transmit information which is not yet available from the source. This effect is utilized here, for example, by transmitting synchronization data instead of the source data. A further solution involves transmitting other header or user data as well, instead of the synchronization data. The greater the channel data rate, the shorter it is possible to select the temporary register.

Further advantages, features and application possibilities of the present invention are revealed from the following exemplary embodiments, which are described with reference to the drawing and tables.

The terms and reference numerals used in the appended list of reference numerals are used in the specification, in the claims, in the abstract and in the drawing.

Hereinbelow, the invention is described in greater detail on the basis of exemplary embodiments with reference to the drawing, in which:

Fig. 1 shows a 16-QAM signal constellation;

Fig. 2 shows a hexagonal signal constellation;

Fig. 3+6 show a block diagram of a circuit arrangement used for improved data transmission with the aid of the efficient use of multilevel modulation methods;

Fig. 4 shows a table 1, which indicates the probabilities p1, p2, p3, p4 for the signal points in Fig. 2; and

Fig. 5 shows a table 2, which represents the mapping of the binary data to the signal points and vice versa.

As was already stated, known transmission methods employ orthogonal basis functions to represent the signal to be transmitted. In this case, a message signal s(t) is represented as the sum of orthogonal basis functions. A message signal can be regarded as a point in a K-dimensional space. The entirety of all permissible signal points is referred to as a signal constellation, the "16-QAM" signal constellation shown in Fig. 1, which represents one of the two-dimensional signal constellations, being especially popular.

If a signal constellation has a total of M signal points, $M_j$ of each of which have the signal energy $E_j$, and if the probability for the occurrence of such a signal point is equal to $P_j$, then, by setting the probabilities according to the formula given below, one obtains the values which are optimal according to power/information rate for that power. The value L indicates how many different energy levels occur in total.

$$p_j = p_1 \left(p_L/p_1\right)^{(E_j-E_1)/(E_L-E_1)} \qquad j = 1,2,\ldots, L \text{ and } E_{j+1}>E_j$$

Given here as an example is the hexagonal signal constellation in Fig. 2. For reasons of normalization, the minimum distance between the signal points is selected as one. Here, there are $L = 4$ energy levels. $E_1 = 0$, $E_2 = 1$, $E_3 = 3$ and $E_4 = 4$. There is one signal point with signal energy zero ($M_1 = 1$) and 6 signal points each with signal energies 1, 3 and 4, i.e., $M_2 = M_3 = M_4 = 6$.

For example, to map a data stream with a defined probability distribution to the corresponding signal points, use is made of a loss-free data compression algorithm, such as the Huffman method. This data compression algorithm ensures that the corresponding signal points occur with the aforementioned probability. The Huffman method is described, for example, in D.A. Huffman, "*A Method for the Construction of Minimum Redundancy Codes*", Proc. IRE, Vol. 40, Sept. 1952, pages 1098-1101. In the following example, a binary bit sequence, in which the probability for ones and zeros is identical and in which the bits are statistically independent, is recoded, and specifically in such a way that with the signal constellation shown in Fig. 2 with 19 signal points, on average $H = 4$ bits per signal point can be efficiently transmitted. From the indicated table 1 according to Fig. 4, one then obtains the probabilities for the occurrence of the individual signal points. The use of a data compression method leads to a correspondence of the kind found, for example, in table 2. With the correspondence shown in table 2 according to Fig. 5, one comes very close to the optimal mean signal energy $E_S = 1.7224$. One obtains a mean signal energy of 1.8125. By comparison, the conventional 16-QAM signal constellation has a mean signal energy of 2.5. In other words, in comparison with the known 16-QAM, one obtains an improvement of 10 lg (2.5/1.8125) dB, that is, approximately 1.4 dB, with this simple method. With more complex correspondences, one can come as close as one wishes to the optimal value. For the purpose of illustration, with the above correspondence, the bit sequence 01110100001111100111011110001 produced with a coin would then be transmitted with the signal points $Z_{32}$ $Z_1$ $Z_{25}$ $Z_{23}$ $Z_{25}$ $Z_{21}$ $Z_{24}$ $Z_{25}$. $Z_1$ is the signal point with energy zero; $Z_{2j}$, where $j = 1..6$, are the signal points with energy 1; $Z_{3j}$ are the signal points with energy 3 and $Z_{4j}$ are the points with energy 4.

The decoding after transmission follows accordingly.

In the following, the construction of a circuit arrangement for implementing the above-described method is explained in greater detail with reference to a block diagram according to Fig. 3.

It is assumed that a data source 1 supplies a data stream 2. A recoder 3 then ensures that a modulator 4 selects the corresponding signal points with the correct probability. After data stream 2 has been transmitted via a transmission channel 5, there follows, after a downstream demodulator 6, the corresponding inverse operation with the aid of a recoder 7, whereupon data stream 2 finally arrives at a data sink 8. The respective data stream 2 is depicted on the connecting/transmission lines or channels between components 1, 3 through 8 by arrow points on the respective lines/channels.

In the recoding of the incoming source bit stream to the signal points which are transmitted through the channel, a temporary register (not shown) is inserted as buffer that is used to adapt the bit rate, which fluctuates as a function of time due to the transmission through the channel, to the bit rate of the source data. In each implementation in the form of a circuit, the temporary register or buffer has a defined length, this possibly leading in practice to a problem of overflow. This problem can be solved by selecting the channel data rate to be somewhat greater than the source data rate. It is therefore possible, with relatively little effort and expense, for the buffer length or the temporary-register length to be specified so that there is only a negligible small (known) probability of a buffer overflow or temporary-register overflow.

If the channel data rate is selected to be slightly greater than the source data rate, it may occur in the practical implementation of a circuit arrangement that the channel will be ready to transmit information which is not yet available from the source.

This effect can be advantageously utilized by transmitting synchronization data instead of the source data. Furthermore, other header or user data can also be transmitted instead of the synchronization data. The greater the channel data rate in relation to the source data rate, the shorter it is possible to select the temporary register or temporary buffer.

A further solution to this problem of buffer overflow or underflow is to provide two or possibly more recoding tables in recoder 3, the one table leading to a channel data rate which is greater than the source data rate and the other table leading to a channel data rate which is lower than the source data rate. Recoder 3 can then be controlled as a function of the state of the temporary storage. That is, if the temporary storage is in danger of overflowing, the channel data rate is selected which is greater than the source data rate. In the opposite case, if there are almost no data left in the temporary storage, the channel data rate is selected which is lower than the source data rate.

Fig. 6, which is derived from Fig. 3, shows the most common case, which includes the above possibility. The possibility of controlling recoder 3 as a function of temporary storage 9 is indicated in Fig. 6 by the broken line from the temporary storage with control unit/processing unit 9 to recoder 3. Likewise shown in Fig. 6 is an optional second data source 1' (for the special case when the rate of this data source is equal to zero, this source disappears). As described above, second data source 1' permits the transmission of additional data. The broken lines from recoder 3 to second data source 1' indicate the manner in which, for example, check data can be integrated into the method for the purpose of correcting errors. The source data rate and the rate of the generated error detection characters together must, on average, not exceed the mean channel data rate. Analogous to second data source 1' and the temporary storage with control/processing unit 9, a second data sink 8' and a temporary storage with control/processing unit 9' are inserted between data sink 8 and inverse recoder 7.

To further improve the method, it is possible to use special coding methods which

have been designed, for example, for QAM or hexagonal signal constellations and which can be found in the articles K. Huber, *"Codes over Gaussian Integers"*, IEEE Transactions on Information Theory, Vol. 40, No. 1, January 1994, pp. 207-216 and K. Huber, "*Codes over Eisenstein-Jacobi Integers*", Finite Fields: Theory, Applications and Algorithms, (Las Vegas 1993), Contemporary Math. Vol. 168, American Math. Society, Providence, R1, pp. 165-179 as well as K. Huber, "*Codes over Tori*", IEEE Transactions on Information Theory, Vol. 43, No. 2, March 1997, pp. 740-744.

**List of reference numerals**

| | |
|---|---|
| 1,1' | Data source |
| 2 | Data stream |
| 3 | Recoder |
| 4 | Modulator |
| 5 | Channel |
| 6 | Demodulator |
| 7 | Inverse recoder |
| 8,8' | Data sink |
| 9,9' | Temporary storage with control/processing unit |

Patent Claims

1. A method for improved data transmission and for efficient use of multi-level modulation methods which employ orthogonal basis functions to represent a signal to be transmitted,
characterized in that signal points having a defined signal energy of a signal constellation are selected according to set and/or selected probabilities in order to optimize the signal energy and/or data rate.

2. The method as recited in Claim 1,
characterized in that source coding methods, such as the known Huffman method, are employed for adapting data sequences for the purpose of using orthogonal methods.

3. The method as recited in one of Claims 1 or 2, characterized in that, for protection against transmission errors, use is made of an error-correcting code, adapted to the modulation method and channel, whose error detection characters are inserted with the aid of a second data source (1').

4. The method as recited in Claim 3,
characterized in that the error-correcting code is a block code.

5. The method as recited in Claim 3,
characterized in that the error-correcting code is a convolution code.

6. The method as recited in Claim 4,
characterized in that the block code is a code over Gaussian integers modulo a Gaussian number.

7. The method as recited in Claim 4,

characterized in that the block code is a code over Eisenstein-Jacobi integers modulo an Eisenstein-Jacobi number.

8. The method as recited in one of Claims 1 through 7, characterized in that the input data stream is encrypted.

9. A circuit arrangement for implementing the method for improved data transmission with the aid of orthogonal functions,
characterized in that, downstream of a data source (1) for a data stream (2) is a recoder (3) whose output is connected to a modulator (4) for selection of the corresponding signal points with the correct probability;
the output of the modulator (4) is connected to the input of a channel (5) whose output is connected to the input of a demodulator (6) which is followed by an inverse coder (7) for executing the operation inverse to that of the coder (3); and
the output of this coder (7) is connected to a sink (8) for the data stream (2).

10. The circuit arrangement for implementing the method for improved data transmission with the aid of orthogonal functions as recited in one of Claims 1 through 8,
characterized in that provision is made for a temporary storage with a control/processing unit (9) which can cause the recoder (3') to switch between at least two recoding tables such that there is no storage overflow, combined with the corresponding inverse devices (8' and 9') on the receiver and data-sink sides.

11. The circuit arrangement as recited in one of Claims 9 or 10 for implementing the method for improved data transmission with the aid of orthogonal functions,
characterized in that the output of the modulator (4) is connected in buffered

manner to the input of the channel (5), in particular via a temporary register or a buffer.

12. The circuit arrangement as recited in Claims 9, 10 or 11, characterized in that a second data source (1') supplies the temporary storage with additional data which are either user, synchronization or check data.

13. A method according to Claim 1 for operating a circuit arrangement as recited in one of Claims 9 or 10, characterized in that the channel data rate is selected to be greater than the source data rate.

14. The method as recited in Claims 1 and 13, respectively, characterized in that if no source bits are present at the circuit, synchronization data are transmitted.

15. The method as recited in Claims 1 and 13, respectively, characterized in that if no source bits are present at the circuit, other housekeeping or user data are transmitted.

Abstract

The invention relates to a method and a circuit arrangement for efficient use of multistage modulation methods using orthogonal base functions for the representation of a signal to be transmitted. A 16-QAM signal constellation can be used, for instance, in a simple and optional way, for transmitting at low data rates. The circuit arrangement corresponding to said method comprises a source (1) which supplies a data stream (2) and is connected to a code converter (3) for converting the data stream. The output of the code converter (3) is connected to a modulator (4) in which the corresponding signal points are selected with the right probability. The data stream (2) is then transmitted over a channel (5), and a demodulator (6) situated downstream from a code converter (7) carries out the inverse operation.

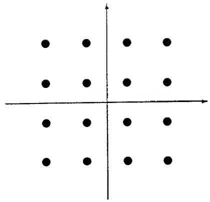

FIG. 1

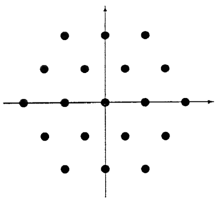

FIG. 2



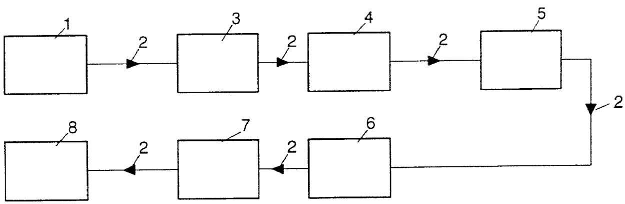


FIG. 3

**Table 1**

| $E_s$ | $p_1$ | $p_2$ | $p_3$ | $p_4$ | $H$ |
|---|---|---|---|---|---|
| 2.526 | 1/19 | 1/19 | 1/19 | 1/19 | 4.2479 bit |
| 1.7224 | 0.1313 | 0.08534 | 0.03603 | 0.02341 | 4 bit |
| 0.8118 | 0.3372 | $9.931 \cdot 10^{-2}$ | $8.614 \cdot 10^{-3}$ | $2.537 \cdot 10^{-3}$ | 3 bit |
| 0.3962 | 0.6133 | $6.370 \cdot 10^{-2}$ | $6.870 \cdot 10^{-4}$ | $7.135 \cdot 10^{-5}$ | 2 bit |

FIG. 4

**Table 2**

| Point | Binary data |
|---|---|
| $z_1$ | 100 |
| $z_{21}$ | 1101 |
| $z_{22}$ | 1100 |
| $z_{23}$ | 1111 |
| $z_{24}$ | 1110 |
| $z_{25}$ | 001 |
| $z_{26}$ | 000 |
| $z_{31}$ | 01111 |
| $z_{32}$ | 01110 |
| $z_{33}$ | 10101 |
| $z_{34}$ | 10100 |
| $z_{35}$ | 10111 |
| $z_{36}$ | 10110 |
| $z_{41}$ | 01001 |
| $z_{42}$ | 01000 |
| $z_{43}$ | 01011 |
| $z_{44}$ | 01010 |
| $z_{45}$ | 01101 |
| $z_{46}$ | 01100 |

FIG. 5

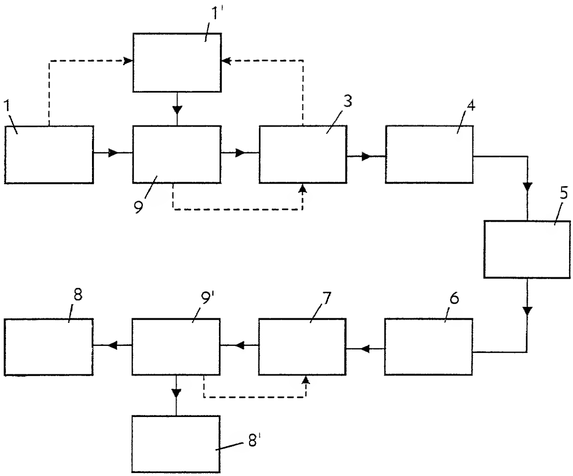


FIG. 6

| U.S. DEPARTMENT OF COMMERCE<br>PATENT AND TRADEMARK OFFICE | |
|---|---|
| **DECLARATION AND POWER OF ATTORNEY** | ATTORNEY'S DOCKET NO.<br>**2345/129** |

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name,

I believe I am an original, first, and joint inventor of the subject matter that is claimed and for which a patent is sought on the invention entitled **METHOD AND CIRCUIT ARRANGEMENT FOR IMPROVED DATA TRANSMISSION**, the specification of which was filed as International Application No. **PCT/EP98/04789** on **31 July 1998**.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

PRIOR FOREIGN APPLICATION(S)

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

| COUNTRY | APPLICATION NUMBER | DATE OF FILING (day, month, year) | DATE OF ISSUE (day, month, year) | PRIORITY CLAIMED UNDER 35 U.S.C. § 119 |
|---|---|---|---|---|
| **Germany** | **197 48 880.3** | **6 November 1997** | | **YES** |

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I declare that all statements made herein of my own knowledge are true and all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title 18 of the United States Code and that such willful statements may jeopardize the validity of the application or any patent issuing thereon.

| | | | |
|---|---|---|---|
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| Signature | Klaus Huber | Date | 20th March 2000 |